Malaysian Journal of Sustainable Environment
Special issue, June (2025), 81-102
doi: 10.24191/myse.v12i2.7059

IDENTIFYING OPTIMAL WINDOW-TO-WALL RATIO (WWR) AND WINDOW-TO-FLOOR RATIO (WFR) FOR TYPICAL HIGHER EDUCATIONAL CLASSROOMS TO ADDRESS DEFICIENCIES IN DAYLIGHTING DESIGN

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Received: 18 June 2024
Accepted: 25 September 2024
Published: 30 June 2025

ABSTRACT

Daylighting plays a crucial role in creating conducive learning environments in higher education classrooms, enhancing visual comfort, student performance, well-being, and overall satisfaction. However, many educational facilities suffer from poor daylighting design, leading to uneven illumination, glare, and overdependence on artificial lighting. This study addresses these issues by investigating current daylighting conditions, particularly focusing on Window-to-Wall Ratio (WWR) and Window-to-Floor Ratio (WFR), which significantly influence natural light distribution. The research aims to assess the effectiveness of existing glazing configurations and propose optimised WWR and WFR values using both field measurements and simulation through Building Information Modelling (BIM) software, specifically Autodesk Revit. Field data from two classrooms equipped with tinted glass were compared to daylight factor (DF) standards from MS1525 (2019) and WFR recommendations of UBBL (1984). Findings reveal that while WWR and WFR exceeded the minimum threshold of 20%, *daylight penetration, and uniformity varied, with some areas suffering from insufficient light and glare. This research highlights the need for improved daylighting design, offering evidence-based recommendations to optimize natural light in educational spaces, enhancing comfort and energy efficiency.*

Keywords: *Daylighting design, Higher Education classrooms, Simulation, Window-to-Floor Ratio, Window-to-Wall Ratio*

INTRODUCTION

Daylighting is a critical aspect of designing educational environments, as it significantly affects students' learning experiences, health, and overall well-being. Natural light contributes not only to visual comfort but also to improved student focus, mood, and academic performance. Despite its recognized benefits, many higher education classrooms still suffer from poor daylighting design, leading to issues such as uneven light distribution, glare, and overreliance on artificial lighting. These deficiencies can negatively impact the learning environment and hinder student performance. Therefore, it is essential to optimize daylighting strategies in such spaces to improve both energy efficiency and learning outcomes.

Window-to-Wall Ratio (WWR) and Window Floor Ratio (WFR) are two key parameters that play a fundamental role in the design and performance of daylighting in classrooms. These ratios directly influence the amount and quality of natural light entering interior spaces. Studies by Chen et al. (2021) and Lee and Kim (2019) have highlighted the importance of natural lighting in enhancing student attentiveness, mood, and academic achievements. On the other hand, research has shown that insufficient daylight leads to increased energy consumption, eye strain, fatigue, and greater dependency on artificial lighting (Reinhart & Walkenhorst, 2016; Ren et al., 2020). Therefore, determining the optimal WWR and WFR for higher education classrooms is crucial for maximizing the benefits of daylight while minimizing its drawbacks, such as glare and excessive heat.

While there is ample research on the benefits of natural light in educational settings, applying these findings to real-world classroom design remains challenging. Classrooms vary greatly in terms of size, layout, and architectural features, making it difficult to develop universal guidelines. Although organizations such as the Illuminating Engineering Society (IES) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) offer general recommendations for daylighting design, they often fail to address the unique needs and constraints of educational facilities (IES, 2021). This gap necessitates a tailored approach to daylighting design that considers the specific context of higher education institutions.

In response to these challenges, this study adopts a data-driven approach to identify the optimal WWR and WFR configurations for higher education classrooms. By utilizing advanced daylight simulation tools, This research aims to develop empirically based design recommendations that maximize natural light ingress in educational spaces. The goal is to provide actionable insights that integrate daylighting design principles into the architectural and operational frameworks of higher education institutions, ultimately creating more comfortable and effective learning environments for students and educators.

The following sections of this paper will review existing literature on daylighting in educational facilities, particularly focusing on the challenges faced in higher education classrooms. The methodology will then outline the case studies, simulation techniques, and performance metrics employed in the research. Finally, the results will present optimal WWR and WFR configurations derived from parametric analysis and sensitivity assessments, offering practical recommendations for daylighting design in educational settings.

LITERATURE REVIEW

The influence of natural lighting on student performance, health, and well-being is well-documented. Over the past five years, research has increasingly focused on the need to optimize daylight in classrooms, emphasizing its benefits and the challenges of effective daylighting design. However, there remains a gap in the practical application of these insights, particularly concerning the roles of Window-to-Wall Ratio (WWR) and Window Floor Ratio (WFR) in achieving optimal daylighting.

Lee and Kim (2019) conducted a comprehensive meta-analysis of daylighting's impact on student success, finding that sufficient natural light enhances academic performance, cognitive function, and mood regulation. Their study highlighted how classrooms with ample daylight exhibit higher student engagement and attentiveness, drawing a clear link between daylighting and educational effectiveness. Similarly, Chen et al. (2021) explored the physiological and psychological effects of daylighting, using wearable biosensors and subjective evaluations. Their research demonstrated that students exposed to more natural light experienced lower stress levels, reduced fatigue, and improved sleep quality, thus highlighting the importance of daylighting for overall student well-being.

Despite the growing body of research supporting these findings, many higher education classrooms still lack adequate natural light. Reinhart and Walkenhorst (2016) identified significant deficiencies in daylighting within university classrooms, attributing the poor daylighting performance to suboptimal WWR and WFR configurations, misaligned building orientation, and obstructed window views. Their findings emphasized the need for improvements in daylighting design, particularly in higher education settings where architectural constraints often limit natural light penetration.

Ren et al. (2020) further investigated the benefits of daylight harvesting in higher education facilities, showing that it significantly reduces energy consumption and reliance on artificial lighting. Using building energy simulations and life-cycle cost analyses, they demonstrated that optimized daylighting design not only enhances occupant comfort and well-being but also contributes to lower carbon emissions and operational costs. However, they noted that without the proper balance of WWR and WFR, the potential energy savings and daylighting benefits may not be fully realized.

While numerous studies have highlighted the importance of natural light, there is a notable gap in research specifically addressing the roles of WWR and WFR in daylighting design. WWR and WFR are critical parameters that directly influence how daylight enters and distributes within space, yet their optimal configurations are highly dependent on site-specific factors, including building orientation, geographic location, and climate conditions. ASHRAE (2020) and IES (2021) provide general guidelines for daylighting design, but they often lack specificity when it comes to the unique requirements of higher education classrooms. This suggests a need for further research that incorporates advanced simulation tools to determine the ideal WWR and WFR values for educational settings.

Recent studies that have delved into WWR and WFR provide valuable insights. For instance, Kostiuk et al. (2018) demonstrated how variations in WWR affect daylight penetration and visual comfort in different building typologies. Their work revealed that WWR plays a crucial role in controlling daylight ingress, but that an overly high WWR can lead to glare issues and heat gain, while a low WWR can result in insufficient lighting. Similarly, Mazhar and Zhang (2020) analysed WFR in the context of classroom design and found that optimal WFR ratios can improve uniform light distribution, thus enhancing visual comfort without compromising energy efficiency.

In conclusion, the literature underscores the critical importance of natural daylight in educational environments, as well as the complex challenges in designing effective daylighting solutions. While substantial research has been conducted on the general benefits of natural light, the roles of WWR and WFR in optimizing daylighting remain underexplored. Further research is required to bridge this gap, particularly using site-specific evaluations and advanced daylight simulation techniques to develop empirically-based design recommendations. Such efforts will contribute to creating more sustainable, comfortable, and effective learning environments in higher education classrooms.

Guidelines for Daylighting in Buildings

Many daylighting standards and guidelines have been established in Malaysia. The MS1525 specifies educational lighting. The UBBL (1984) recommends the WFR for learning areas. Table 1 demonstrates that MS1525, PWD, and IESNA recommend 300 to 500lux for normal reading in frequent classroom contexts.

Table 1. Illumination Level Recommendations

Learning space	Standards and Guidelines		
	MS1525 (lux)	JKR (lux)	IENSA (lux)
MS1525 (lux)	JKR (lux)	IENSA (lux)	MS1525 (lux)
MS1525 (lux)	JKR (lux)	IENSA (lux)	MS1525 (lux)

MS1525 (lux)	JKR (lux)	IENSA (lux)	MS1525 (lux)

Source: Syaheeza et al., (2018)

Daylighting Calculations

The Daylight Factor (DF) measures indoor-to-outdoor daylight under cloudy skies (Nedhal et al., 2016). Working planes and surfaces' perceived internal illuminance is measured by the DF. The design makes it simple, user-friendly, and reliable for Malaysia's tropical climate. MS1525 (2019) represents Equation 1 as the DF formula and Table 2 as the scale pf DF value. Table 2 shows that maximum room illumination, glare, and thermal comfort are achieved with DFs between 1.0% and 3.5% (MS1525, 2019).

$$DF = \frac{E_{internal}}{E_{external}} \times 100\% \qquad (1)$$

Table 2. Scale of DF value (%)

DF (%)	Lighting	Glare	Thermal comfort	Description
> 6.0	Intolerable	Intolerable	Uncomfortable	High daylight illuminates the room. Daytime artificial lighting is rare, although solar heat gain and glare can cause thermal issues.
3.5 – 6.0	Tolerable	Uncomfortable	Tolerable	
1.0 – 3.5	Acceptable	Acceptable	Acceptable	Moderate daylight illuminates the room. Well-balanced lighting and temperature. Due to furniture configuration, gloomy areas require artificial lighting.
< 1.0	Perceptible	Imperceptible	Acceptable	Room looks gloomy, artificial lighting is needed most of the time.

Source: MS1525 (2019)

Section 39(3) of the UBBL requires natural light and ventilation in educational spaces. Maintaining 20% of the WFR should do this. Glazing proportion is measured in two ways. The WFR is the ratio of a building's glass area to its floor area. At least 10% of the WFR should enable natural airflow. Equation 2 uses glass area and gross interior floor area to calculate

WFR (Zain-Ahmed et al., 2002). ASHRAE (2020) defines WWR as the full wall-divided window space. Building energy efficiency depends heavily on the WWR. Equation 3 calculates WWR by considering wall area and outside wall area.

$$\text{WFR (\%)} = \frac{\sum \text{Glazing area (m2)}}{\sum \text{Gross interior floor area (m2)}} \quad (2)$$

$$\text{WWR (\%)} = \frac{\sum \text{Glazing area (m2)}}{\sum \text{Gross exterior wall area (m2)}} \quad (3)$$

Climate, building type, and project goals affect WWR and WFR numbers. Architectural, engineering, and building experts use the ranges as standard recommendations and guidelines for sustainable design. According to various research studies, daylighting design often uses WWR percentages of 20% to 40% and WFR percentages of 5% to 15% for classrooms. Again, the percentage depends on daylight levels, building orientation, and exterior shading.

METHODOLOGY

A fieldwork measurement was done to assess daylighting in typical higher education classrooms. Purposive sampling selected classrooms that correctly represented several disciplines. This selection procedure examined building orientation, window orientation, and architectural differences. Two (2) classrooms at an educational building were picked based on Table 3, and all were chosen based on availability.

Table 3. Selected Case Study Classrooms and Characteristics

Classrooms	Outdoor view	Indoor view	Façade Design	Room size
Classroom 1			•Single-sided window (tinted glazed – East) •Single-loaded corridor	11.5 meter (length) x 9.0 meter (width)

Classroom 2			•Single-sided window (tinted glazed – Northwest) •Double-loaded corridor	12.0 meter (length) x 6.0 meter (width)

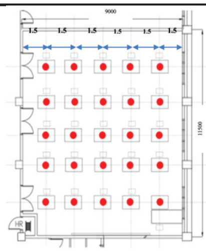
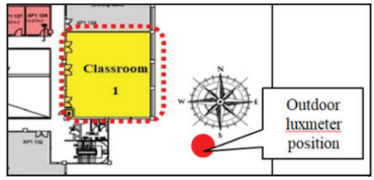
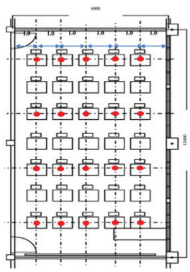
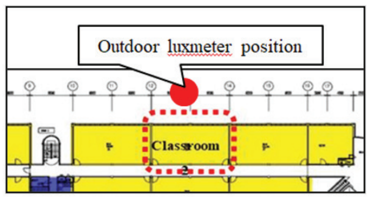
Source: Author

Field Measurement Study

The classrooms were measured indoors and outdoors in July and August. Each classroom was measured for five (5) days from 8 a.m. to 5 p.m. The early step of the study found daylighting failures in each classroom, which were assessed to evaluate inadequate daylighting. The instruments were measured at 0.75 metres, similar to a desk, indoor and outdoor measurements were conducted in overcast and sunny conditions. Distance from the window and daylight zones determined the number of measuring points. Regular 30-minute indoor and outdoor illumination measurements were taken throughout the day.

Table 4 details the fieldwork measurement locations for indoor and outdoor light measurements in two classrooms. Classroom 1, with a 103.5 m² GFA and 3.2 m height, features 25 1.5-meter-apart measuring sites in a 9000 mm by 11500 mm room. Red circles show light measuring spots on the grid. Classroom 2, with a 72.0 m² GFA and 3.2 m height, features 20 red circle-marked measurement points 1.0 metres apart in a 6000 mm x 12000 mm room. Measurements are done in classrooms with the same ceiling height (3.2 metres) for consistent comparison. The thorough grid structure for indoor measurements covers all classroom light levels. Indoor readings are compared to outdoor lighting settings using outdoor lux metre placements that reflect classroom natural light.

Table 4. Fieldwork Measurement Location

Classrooms	Indoor	Outdoor
Classroom 1 (C1) •25 points •GFA = 103.5m2 •Height = 3.2m 		 
Classroom 2 (C2) •20 points •GFA = 72.0m2 •Height = 3.2m		 

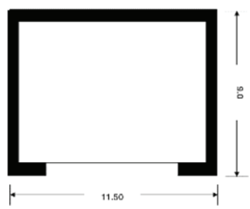
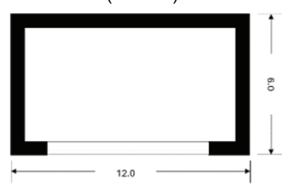
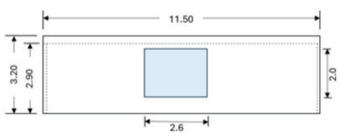
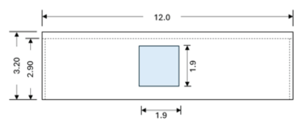
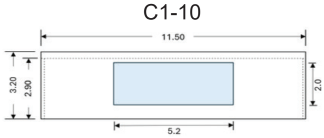
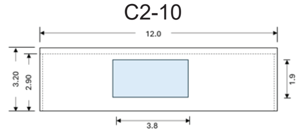
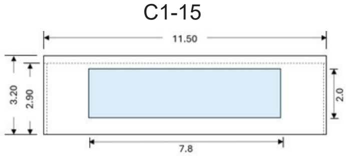
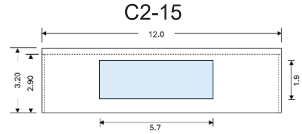
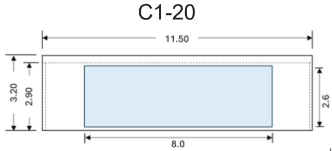
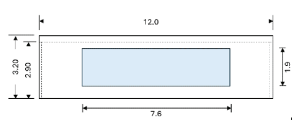
Source: Author (2025)

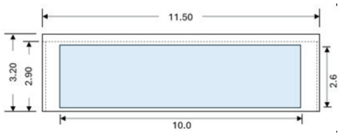
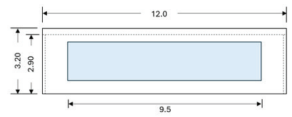
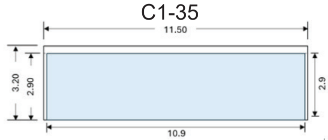
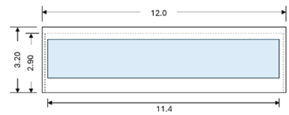
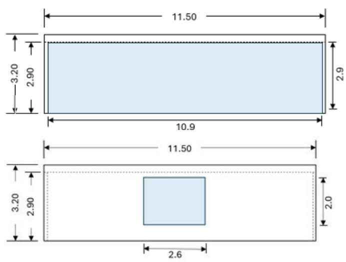
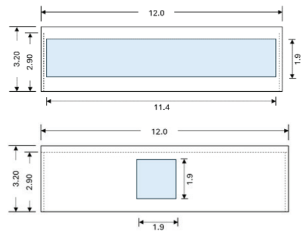
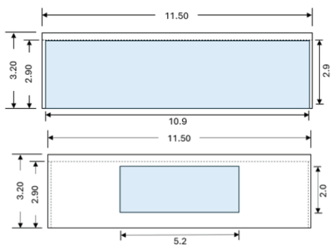
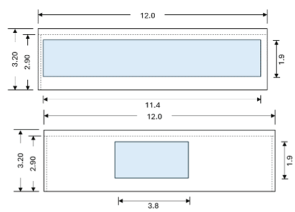
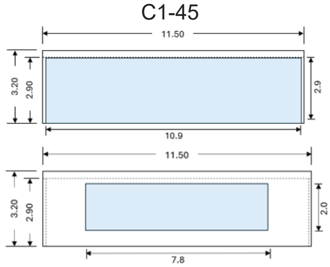
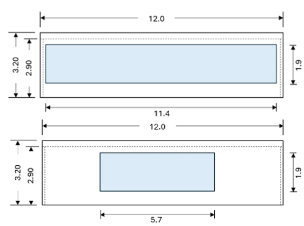
Simulation Approach

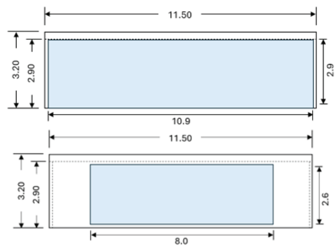
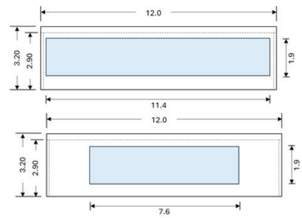
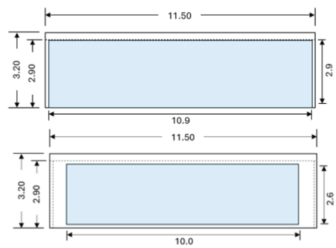
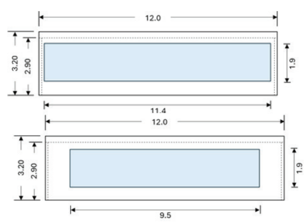
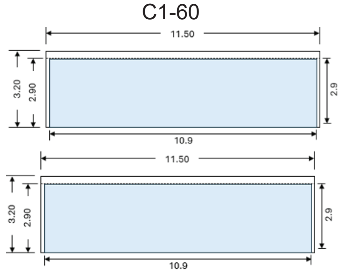
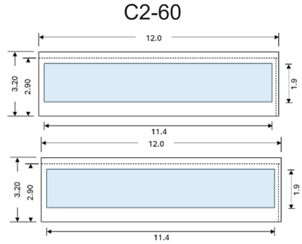
BIM software like Autodesk Revit was used to create parametric models of the sampled classrooms. The Revit models were accurate because they were created using precise measurements and visual evidence from on-site investigation. Each classroom's walls, windows, doors, and interior parts were reconstructed in Revit. References included precise measurements and digital photographs. The height of the ceiling, room orientation, and any barriers that could impede natural light were captured with special attention.

The simulations provided quantitative data on daylighting measures such the DF, allowing WWR and WFR setup comparisons. This research identified the best daylighting approaches to fix classroom design flaws by methodically manipulating these factors while maintaining other variables. To determine how window size affects illuminance, 24 samples were chosen. Classrooms 1 and 2 had the same floor space and window glass type (tinted glass), but the window size was raised to see how it affected DF, starting with 5% WFR. The examined samples are in Tables 5 and 6.

Table 5. Analysed Samples based on Window Size and WFR Value

Classrooms	Classroom 1	Classroom 2
Actual Plans	Wall Thickness (0.25m) 	Wall Thickness (0.25m) 
WFR = 5%	C1-5 	C2-5 
WFR = 10%	C1-10 	C2-10 
WFR = 15%	C1-15 	C2-15 
WFR = 20%	C1-20 	C2-20 

WFR = 25%	C1-25 	C2-25 
WFR = 30%	C1-35 	C2-35 
WFR = 35%	C1-35 	C2-35 
WFR = 40%	C1-40 	C2-40 
WFR = 45%	C1-45 	C2-45 

WFR = 50%	C1-50 	C2-50 
WFR = 55%	C1-55 	C2-55 
WFR = 60%	C1-60 	C2-60 

Source: Author (2025)

In Tables 5, examples C1-5 to C1-60 represent Classroom 1 and C2-5 to C2-60 Classroom 2. These samples have tinted glass and varying window sizes. Room natural light depends on window size. Both WFR and WWR are tested between 5% and 60% and 9% and 85%. Daylighting parameters including sky type, work plane height, and desk height must be determined for a precise simulation. Table 6 lists analytical parameters.

Table 6. Simulation Settings

Data	Value
Simulation software	Autodesk Revit 2023
Extension	Lighting Analysis
Sky Model	CIE Intermediate Sky

Work plane height	0.75 meter
Windowsill height	0.70 meter – 0.50 meter
Window Glass type	Tinted clear glass

Source: Author, (2025)

Limitations of the Study

This research has several limitations that may affect the generalizability of its findings. First, the study is limited to two classrooms in a single educational building, which may not represent the diverse architectural variations across higher education institutions. The research's geographic and climatic context further restricts its applicability to other regions. Additionally, the focus on tinted glass limits insights into how other glazing types, such as clear or reflective glass, impact daylight performance. Field measurements were conducted only during the summer months and specific hours, potentially missing seasonal variations. The reliance on fixed assumptions in daylighting simulations, like the CIE Intermediate Sky model, may not fully capture real-world conditions.

Furthermore, the study focuses on optimizing WWR and WFR, overlooking other factors like shading devices, surface reflectance, and occupant behaviour, which also influence daylighting. The absence of direct occupant feedback limits understanding of subjective factors such as glare and visual comfort. Future research should include broader sample sizes, varied contexts, and real-world feedback to enhance the robustness and relevance of the findings.

RESULTS

Results of Fieldwork Measurement

The analysis findings are deliberated based on the average measurement taken over a period of five days. Therefore, the analysis results also include the DF, WFR, and WWR for each classroom that was analysed.

Table 7. Average Indoor Illuminance level, DF, WFR and WWR Value

Value	Min. (lux)	Max. (lux)	Min. DF (%)	Max. DF (%)	Average DF (%)	WFR (%)	WWR (%)
C1	27	1690	0.1	5.9	0.5	6.26	17.61
C2	16	295	0.1	1.2	0.3	16.0	30.0

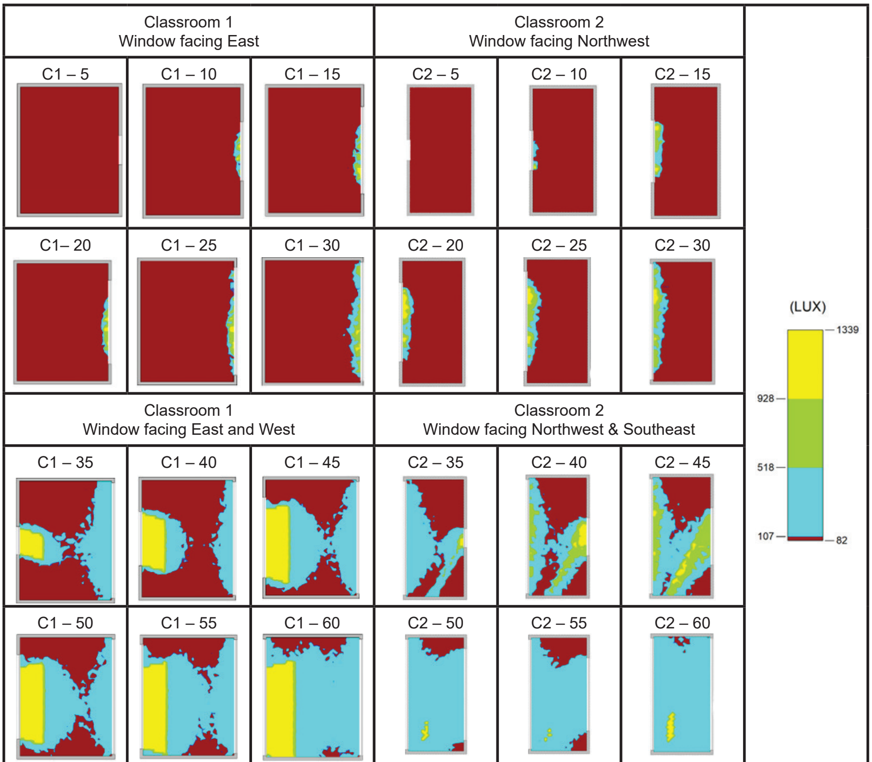
Source: Author (2025)

Indoor illumination should be 300–500 lux, according MS 1525 (2019). In Table 7, Classrooms 1 and 2 have below-permitted indoor lighting. The MS1525:2019 range is 1.0% to 3.5%. Ideal illumination, glare, and thermal comfort are achieved with this assortment. DF values in Classrooms 1 and 2 were below the minimum in Table 8. WFR/WWR should not be below 20%, according UBBL (1984). If the ratio is under 20%, the back of the room may be dark. In Table 5, Classroom 2's WFR is below UBBL: 1984's recommendation. Windows exceeding 30% WWR may cause building overheating, hence the WWR is slightly suitable. WFR and WWR percentages in Classroom 1 are below UBBL: 1984.

Results of Simulation

Research conducted using Autodesk Revit examines the performance disparities of window sizes in simulation and illumination. By maintaining consistent floor area dimensions, we can specifically examine the impact of window layouts on various metrics. The lighting analysis simulation results for the penetration of single-sided window lighting in Autodesk Revit are displayed in Table 8. The simulations were validated using a 5% WFR threshold, and the floor space of each sample was equivalent to the classrooms in the case studies.

Table 8. Lighting Penetration based on WFR Value



Source: Author (2025)

Table 9. Average DF, lux level and WWR Value Simulation Results

WFR (%)	Samples	Window area (m2)	Floor area (m2)	Min. (lux)	Max. (lux)	Average DF (%)	WWR (%)
5	C1 – 5	5.2	103.5	0.1	112.83	0.1	14.1
10	C1 – 10	10.4	103.5	1.2	139.3	0.2	28.3
15	C1 – 15	15.6	103.5	2.4	142.45	0.3	42.4
20	C1 – 20	20.8	103.5	2.8	141.42	0.3	56.5
25	C1 – 25	26.0	103.5	4.3	148.58	0.4	70.7
30	C1 – 30	31.6	103.5	5.3	174.47	0.5	85.9
35	C1 – 35	36.8	103.5	35.1	1300.2	0.5	50.0
40	C1 – 40	42.0	103.5	29.9	1333.7	0.6	57.1
45	C1 – 45	47.2	103.5	37.3	1341.7	0.6	64.1
50	C1 – 50	52.4	103.5	47.4	1368.9	0.7	71.2
55	C1 – 55	57.6	103.5	52.7	1384.8	0.7	78.3
60	C1 – 60	63.2	103.5	55.4	1413.1	0.8	85.9

5	C2 – 5	3.6	72.0	0.7	102.6	0.1	9.4
10	C2 – 10	7.2	72.0	2.2	153.2	0.3	18.8
15	C2 – 15	10.8	72.0	5.2	170.6	0.4	28.1
20	C2 – 20	14.4	72.0	6.6	167.5	0.6	37.6
25	C2 – 25	18.1	72.0	12.1	181.5	0.6	47.0
30	C2 – 30	21.7	72.0	14.5	183.2	0.7	56.4
35	C2 – 35	25.3	72.0	35.1	546.4	0.8	32.9
40	C2 – 40	28.9	72.0	27.2	239.8	0.9	37.6
45	C2 – 45	32.5	72.0	30.2	228.4	0.9	42.3
50	C2 – 50	36.1	72.0	43.1	1255.7	1.1	47.0
55	C2 – 55	39.14	72.0	45.9	1283.7	1.1	51.0
60	C2 – 60	43.32	72.0	82.4	1338.5	1.2	56.4

Source: Author (2025)

Tables 8 and 9 indicate the average DF for tinted windows in C1 and C2 classrooms across WFR. Number of samples, window area, floor area, minimum and maximum lux, average DF, and WWR are measured. MS1525 recommends DF of 1.0% to 3.5%, whereas UBBL (1984) proposes WFR of 20%.

At a 5% WFR and 5.2 m² window area, the average DF for C1 with a floor area of 103.5 m² is 0.1%, substantially below the permitted range. Window area increases with WFR, reaching 63.2 m² at 60% WFR. The minimum and maximum illuminance values increase with WFR, reaching 1413.1 lux at 60% WFR. Despite the enormous window size, the average DF at 60% WFR is 0.8%, below the recommended limit. WWR rises, reaching at 85.9% at 60% WFR.

While C2, with a smaller floor area of 72.0 m², has a similar WFR-illuminance/DF connection. With a window area of 3.6 m² and 5% WFR, the average DF is 0.1%, which is insufficient. Increasing WFR to 60% and window area to 43.32 m² yields an acceptable average DF of 1.2% per MS1525. The minimum and maximum illuminance values are 0.7 lux at 5% WFR, 82.4 at 60% WFR, and 102.6 to 1338.5. WWR rises to 56.4% at the greatest WFR.

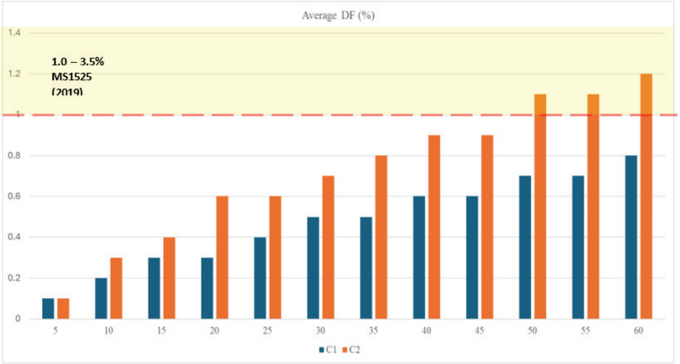


Figure 1. Average DF

Source: Author (2025)

Figure 1 shows C1 DF values as blue bars and C2 as orange bars. The graph shows MS1525 (2019)'s allowable DF range of 1.0% to 3.5% in yellow. A red dashed line indicates the acceptable range's lower limit at 1.0%. For C1, the average DF is 0.1% at 5% WFR and rises to 0.8% at 60% WFR. All WFRs had C1 DFs below the permissible range, notwithstanding this increase. Increasing WFR improves DF more in C2. Starting at 0.1% for a 5% WFR, the DF for C2 rises sharply, above the 1.0% criterion at 50% and reaching 1.2% at 60%, falling below MS1525 (2019) acceptable range.

This comparison shows that despite both classrooms have higher WFR, only Classroom 2 meets MS1525 DFs. Classroom 1, despite similar WFR improvements, fails to attain the minimum necessary DF, suggesting that room size or window design may be influencing daylight penetration and distribution. Classroom 2 uses additional window areas to meet daylighting criteria, highlighting the significance of optimising WFR to improve classroom daylight performance.

DISCUSSIONS

Discussion on Comparing the Fieldwork Measurement and Simulation Results

Table 10. Fieldwork Measurement and Simulation Results Compared with Standard

1.0 % - 3.5 % : MS1525 (2019)						
Minimum 20% WFR : UBBL (1984)						
Classrooms	WFR (%)	WWR (%)	Min. (lux)	Max. (lux)	Min. DF (%)	Max. DF (%)
Actual C1	6.26	17.61	27	1690	0.1	5.9
Actual C2	16.0	30.0	16	295	0.1	1.2
C1 – 5	5	14.1	0.1	112.8	0.004	1.7
C1 – 10	10	28.3	1.2	139.32	0.02	1.7
C1 – 15	15	42.4	2.4	142.5	0.03	1.8
C1 – 20	20	56.5	2.8	141.42	0.04	1.8
C1 – 25	25	70.7	4.3	148.58	0.05	1.8
C1 – 30	30	85.9	5.3	174.47	0.07	1.8
C1 – 35	35	50.0	35.1	1300.2	0.09	1.9
C1 – 40	40	57.1	29.9	1333.7	0.1	1.9
C1 – 45	45	64.1	37.3	1341.7	0.2	1.9
C1 – 50	50	71.2	47.4	1368.9	0.2	1.8
C1 – 55	55	78.3	52.7	1348.8	0.3	2.0
C1 – 60	60	85.9	55.4	1413.1	0.2	2.0
C2 – 5	5	9.4	0.7	102.6	0.01	1.4
C2 – 10	10	18.8	2.2	153.2	0.03	1.6
C2 – 15	15	28.1	5.2	170.6	0.07	2.0
C2 – 20	20	37.6	6.6	167.5	0.1	2.1
C2 – 25	25	47.0	12.1	181.5	0.1	2.2
C2 – 30	30	56.4	14.5	183.2	0.2	2.2
C2 – 35	35	32.9	35.1	546.4	0.2	2.1
C2 – 40	40	37.6	27.2	239.8	0.2	2.2
C2 – 45	45	42.3	30.2	228.41	0.2	2.2
C2 – 50	50	47.0	43.0	1255.7	0.2	2.4
C2 – 55	55	51.0	45.9	1283.7	0.3	2.2
C2 – 60	60	56.4	82.4	1338.5	0.5	2.2

The comparison between fieldwork measurements and simulation results for Classrooms C1 and C2 highlights the significant influence of WFR and WWR on daylighting performance, particularly in spaces with tinted window glass. Table 10 illustrates the discrepancies between actual and simulated daylight factors (DF), as well as the challenges of meeting the MS1525 (2019) DF standard of 1.0% to 3.5% and the UBBL (1984) minimum WFR of 20%.

In Classroom 1 (C1), which has an actual WFR of 6.26% and WWR of 17.61%, the fieldwork measurements revealed a minimum illuminance of 27 lux and a maximum of 1690 lux. The corresponding DF ranged from 0.1% to 5.9%, indicating that the minimum DF was significantly below the recommended MS1525 threshold. Simulation results showed that even with a WFR increase to 60%, the DF values ranged between 0.2% and 2.0%, still falling short of the 1.0% minimum DF requirement. This suggests that simply increasing the WFR is insufficient to meet daylighting standards in C1, likely due to the combination of tinted glass, room size, and window orientation limiting natural light penetration.

Classroom 2 (C2), with an actual WFR of 16.0% and WWR of 30.0%, also showed suboptimal daylighting performance in field measurements, with a DF range from 0.1% to 1.2%. However, simulations indicated more promising outcomes for C2. With a WFR of 20%, the DF ranged from 0.1% to 2.1%, nearing the acceptable range. At 50% WFR, the DF increased to 0.2% to 2.4%, while a 60% WFR resulted in DF values between 0.5% and 2.2%, comfortably within the recommended range. These results suggest that C2 could achieve acceptable daylight levels with appropriate WFR adjustments, despite the use of tinted glass.

Overall, the discussion highlights that Classroom 2 performs better under simulated WFR increases, while Classroom 1 struggles to meet daylighting requirements even at higher WFR values. The findings emphasize the need for additional design modifications in Classroom 1, such as adjustments to window size, orientation, or room proportions, to mitigate the light-reducing effects of tinted glass and improve daylight distribution.

CONCLUSIONS

The analysis of both fieldwork measurements and simulation results for Classrooms C1 and C2 demonstrates the challenges of achieving acceptable daylight factors (DF) as per MS1525 (2019) standards, particularly in spaces with tinted windows. In Classroom 1, the actual WFR of 6.26% and WWR of 17.61% yielded a DF range from 0.1% to 5.9%, with the minimum DF falling below the acceptable range. Even with simulations showing a WFR increase to 60%, the DF remained below 1.0%, indicating that further design interventions are required to meet daylighting standards.

Classroom 2, with a WFR of 16.0% and WWR of 30.0%, also had suboptimal daylighting performance in actual measurements. However, simulation results were more favourable, with a WFR of 50% to 60% yielding DF values within the acceptable range of 1.0% to 3.5%. These findings suggest that C2 could achieve adequate daylighting by optimizing the WFR, while C1 may require additional modifications beyond WFR adjustments, such as changes to window design or room dimensions.

In conclusion, Classroom 2 can meet MS1525 (2019) daylighting standards with WFR adjustments between 50% and 60%, whereas Classroom 1 requires more significant design alterations to address its daylighting deficiencies. This study underscores the importance of considering both WFR and window glass type when optimizing natural light in educational spaces, particularly in classrooms with tinted windows. Future design strategies should prioritize a holistic approach to daylighting, accounting for room dimensions, window orientation, and glass properties to ensure optimal daylight distribution and visual comfort. This study emphasises the importance of WFR and window glass type in optimising natural light in educational environments.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support provided by Universiti Teknologi MARA (UiTM) and thank all faculty members, staff, and participants who contributed to this research.

FUNDING

There is no funding for this research.

AUTHOR CONTRIBUTIONS

All authors made contributions to the conception and design of the study. Wan Nur Hanani Wan Abdullah1, Asniza Hamimi Abdul Tharim2, and Asmat Ismail3 conducted material preparation, data collecting, and analysis. Wan Nur Hanani Wan Abdullah1, Farah Salwati Ibrahim4, and Wan Nur Syazwani Wan Mohammad5 wrote the initial version of the manuscript, and all authors provided feedback on previous versions. Each contributor has thoroughly reviewed and given approval to the final version.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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